LOAN DOCUMENT

PHOTOGRAPH THIS SHEET

DTIC ACCESSION NUMBER

LEVEL

(D)

INVENTORY

Communications Engineering for the ...

DOCUMENT IDENTIFICATION

Sep 96

DISTRIBUTION STATEMENT A

Approved for public release

Distribution Unlimited

DISTRIBUTION STATEMENT

H A N D L E W I T H C A R E

ACCESSION FOR		
NTIS	GRA&I	☑
DTIC	TRAC	☐
UNANNOUNCED		☐
JUSTIFICATION		
BY		
DISTRIBUTION/		
AVAILABILITY CODES		
DISTRIBUTION	AVAILABILITY AND/OR SPECIAL	
A-1		

DISTRIBUTION STAMP

DATE ACCESSIONED

19970114 007

DATE RETURNED

DATE RECEIVED IN DTIC

REGISTERED OR CERTIFIED NUMBER

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-FDAC

DTIC FORM JUN 90 70A

DOCUMENT PROCESSING SHEET

PREVIOUS EDITIONS MAY BE USED UNTIL STOCK IS EXHAUSTED.

LOAN DOCUMENT

DTIC QUALITY INSPECTED 1

17 JAN 1997

COMMUNICATIONS ENGINEERING FOR THE GROUND BASED INTERCEPTOR

Gregory J. Hadynski
Rome Laboratory/Space Communications Branch
525 Brooks Rd.
Rome NY 13441

Abstract

The task of developing a communications system to support the Ballistic Missile Defense Organization's (BMDO) Ground Based Interceptor (GBI) Program is a challenging one. The majority of the challenge stems from the fact that the communications link must be designed to be survivable in the potentially nuclear scintillated environment of a national missile defense (NMD) system. Operation in a potentially nuclear environment requires the use of Extremely High Frequency (EHF) communications technology with a waveform optimized for survivability. A communications system of this type has never been built for an application with the stringent size, weight, and power requirements of a ballistic missile interceptor, but the Air Force's Rome Laboratory is responsible for developing a prototype transceiver for BMDO. The prototype transceiver will consist of 44 GHz uplink components, 20 GHz downlink components, and a modem which is capable of the required waveform.

Background

There are four main components to the Ballistic Missile Defense Organization's (BMDO's) near-term National Missile Defense (NMD) architecture plan: the ground based interceptor (GBI); the ground based radar (GBR); the battle management command, control, & communications (BMC^3) node; and the in-flight interceptor communications system (IFICS). In the current concept of operations, the GBR detects incoming ballistic missiles and alerts the BMC^3 node. The BMC^3 node processes the data received from the GBR, alerts the GBI site of the incoming ballistic missile and provides targeting information to the IFICS. The GBI is launched, receives in-flight target updates (IFTUs) and target object maps (TOMs) from the IFICS while in-flight, locks onto the target ballistic missile when it is close enough for its seeker to be activated, and destroys the incoming missile by impact. This concept of operations is illustrated in Figure 1. While it is not shown in Figure 1, information also flows in the opposite direction. The GBI sends back information to the IFICS such as GBI health and status, acknowledgement of messages from the IFICS, endgame processing data, and possibly terminal imaging of target. Therefore, the communications link between the GBI and the IFICS is a 2-way one.

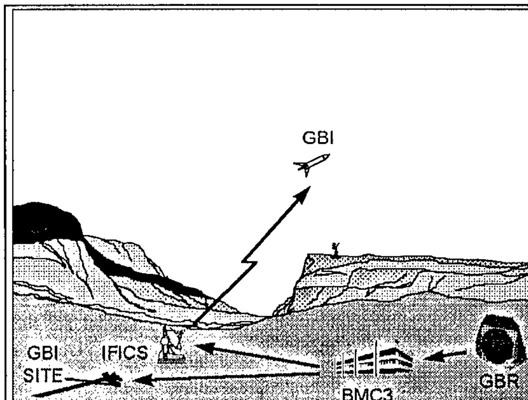

Figure 1 - Current NMD Concept

Implicit in the concept of operations described above is the importance of the communications link between the IFICS and the GBI. Without this communications link, the GBI does not have the necessary targeting information and its mission fails. This communications link must be robust and capable of surviving the potentially nuclear scintillated environment of a NMD system. This requires the use of Extremely High Frequency (EHF) communications technology with a waveform optimized for survivability. Due to its extensive experience in developing communications technologies for ballistic missile defense (BMD) applications as well as other EHF military satellite communications (MILSATCOM) applications, the Air Force's Rome Laboratory was chosen to lead an effort for the development of the required EHF communications system.

Programmatics

The GBI EHF communications system is being developed under Task 3, Communications Engineering, of BMDO Program Management Agreement (PMA) 1267, Ground Based Interceptor. The stated objective of the Communications Engineering Task is to develop a robust 20/44 GHz transceiver to meet the on-board communications requirements for an NMD interceptor.

Rome Laboratory (RL) has been tasked to provide a form, fit, function (F^3) prototype of a communications transceiver for the GBI by the fourth quarter of FY98. To accomplish this, RL chose to divide the program into two phases.

The first phase will provide two functional models of GBI transceivers as well as design plans for building F^3 prototypes. In this first phase, TRW and Harris Corporation are each developing a functional transceiver and F^3 design plan. Since there are currently two competing prime contractors for the GBI's Exo-Atmospheric Kill Vehicle (EKV), Hughes Missile Systems Company and Rockwell International, we must develop F^3 transceiver designs which comply with the physical requirements of each prime contractor's design. In the current program plan, this would be accomplished with a single "one size fits all" transceiver design from each TRW and Harris. However, the possibility of designing unique transceivers for each of the EKV primes is still under consideration.

The second phase will build the F^3 prototype transceiver(s). In the current program plan, the second phase will be the result of a downselect between contractors at the end of the first phase, but this is also subject to change.

Rome Lab's program plan also includes investments in two supporting technologies: the use of low temperature growth Gallium Arsenide technology for improving the power added efficiency of 20 GHz power amplifier devices, and the upgrading of an EHF mobile ground terminal testbed to support GBI flight tests.

GBI Communications Requirements

In the context of this program, a transceiver is defined to include both RF and baseband functions. The block diagram in Figure 2 shows the transceiver functionality in a generic, unclassified form. All functionality will be demonstrated at the end of the two Phase I transceiver programs with the exception of the antennas and encryption/decryption. Both will be addressed as part of the F^3 designs developed during the Phase I, but they are not sufficiently defined to be included in the Phase I demonstration.

More than any other part of the transceiver designs, the antennas are very dependent upon the kill vehicle designs of each EKV prime contractor. What antennas will be used will depend heavily on where each prime decides to locate the antennas on the vehicle, and those decisions have not yet been made.

Encryption/decryption is more of an issue from a bureaucratic standpoint than a technical standpoint. The BMD CSD clearly states what encryption/decryption device will be used. Unfortunately, the program which was developing this device has since been cancelled. Therefore, we need to find a replacement which is acceptable to ourselves as well as the rest of the NMD community, receive approval from the National Security Agency (NSA), and change the standard.

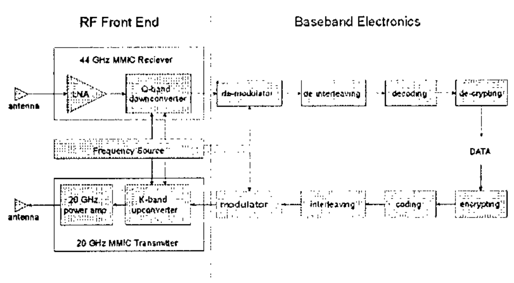

Figure 2 - Transceiver Block Diagram

The GBI Technical Requirements Document (TRD) requires that the GBI will communicate with the ground using a 20 GHz downlink and a 44 GHz uplink. EHF frequency bands are used to provide the desired robustness in a nuclear scintillated environment. These up/downlink frequencies are also standards for EHF MILSATCOM. While the GBI TRD does not dictate an output power level for the GBI's transceiver, link geometry and environment led both EKV prime contractors to establishing an output power requirement of approximately 5 Watts.

The communications waveform requirements for GBI are dictated by the Ballistic Missile Defense Communications Standard (BMD CSD). In BMD CSD nomenclature, the N4 mode waveform will be used for both the uplink and downlink. While details of the waveform are classified, in very general terms the waveform is an M-ary Frequency Shift Keyed (FSK) modulation. As one would expect, the N4 mode also includes functions which are intended to improve performance in a nuclear scintillated environment.

TRW Approach

In their F^3 prototype design concept, TRW divides the functionality of the transceiver into three modules, or slices. The first slice contains all of the tranceiver's RF electronics. The second slice contains all of the transceiver's baseband electronics. The third slice, provides all of the reference frequencies needed by the other two slices. Figure 3 illustrates this design concept.

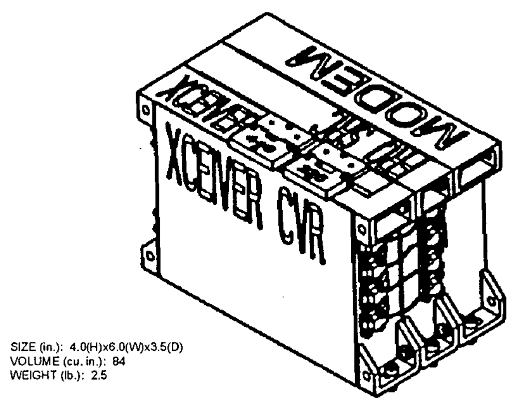

Figure 3 - TRW F^3 Design Concept

In their transceiver design, TRW leverages heavily off of work which they previously performed for RL under their EHF Brassboard Program. The EHF Brassboard Program was part of the tri-service MIMIC Phase 2 Program and combined 20 GHz downlink components, 44 GHz uplink components, 60 GHz crosslink components, and frequency generation components in a brassboard which represented the most compact combination of these functions to date. In order to accomplish this, TRW relied heavily on state-of-the-art monolithic microwave integrated circuit (MMIC) technology to provide the desired miniaturation. While the MMICs developed for the EHF Brassboard Program were intended for use onboard communications satellites, much of the 20 GHz, 44 GHz, and frequency generation components are directly applicable to the requirements for the GBI transceiver.

The only EHF component which TRW is not building itself is the 20 GHz solid state power amplifier (SSPA). They have subcontracted with Texas Instruments to provide a SSPA which produces the required 5 watts output power. Texas Instruments will accomplish this by combining two MMICs, each capable of producing 3 watts of output power, with conventional 3 db hybrid couplers. The ability to provide the full 5 watts by combining only two power devices, helps decrease the complexity, size and weight of TRW's design.

For the baseband portion of the transceiver, TRW is utilizing the "Snapshot Modem" technology which they developed under the RL/BMDO "Programmable Flexible Modem" Program. The "Snapshot Modem" architecture digitizes and stores an entire data sequence. Programmable hardware solutions (field programmable gate arrays) are used for each function (acquisition, tracking, demodulation, decoding, etc.) to retain flexibility to change with evolving system requirements. When system requirements stabilize, the modem design can be readily translated into a radiation hardened application specific integrated circuit (ASIC) if desired. Alternatively, the FPGA implementation can be retained with suitable shielding to protect the FPGA's relatively radiation intolerant electronics.

Harris Approach

In their F^3 prototype design concept, Harris uses the multi-chip module (MCM) packaging concept which they developed on the Sub Miniature Telemetry Technology study program. The MCMs developed for that program were designed for use in a very hostile environment. Each MCM houses an entire subsystem and can be stacked or planar mounted. The MCMs can then be mounted to a payload base plate and interconnected to complete the functional unit assembly. The EKV transceiver functionality will be divided into two stacks of the 3" by 3" by .3" MCMs. Figure 4 illustrates this design concept.

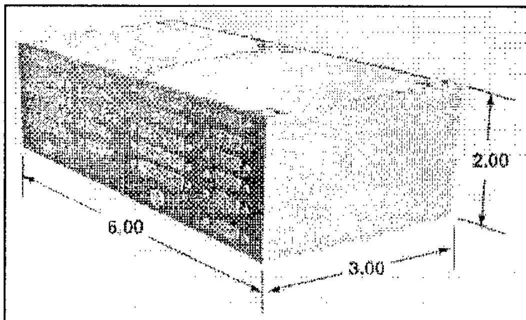

Figure 4 - Harris F^3 Design Concept

Since Harris Corporation does not generally build EHF hardware itself, they chose to subcontract the RF portion of their transceiver to David Sarnoff Research Center. Sarnoff is using existing MMIC components wherever possible as well as some discrete components and combining them using their low temperature co-fired ceramic on metal (LTCC-M) technology for added miniaturization. To provide the necessary 5 watts of output power, Sarnoff will combine 4 MMICs, each capable of producing 1.5 watts of output power, developed by Lockheed Martin Corporation as part of a MIMIC Phase II contract with Wright Laboratory.

Sarnoff's LTCC-M technology provides multi-layer RF, bias, and control routing and enables tight tolerances to be maintained. The benefits of this approach include: minimized surface area, volume, and mass; minimized discontinuities and impedance mismatches between components; improved reliability by minimizing wirebonds; improved unit-to-unit uniformity; and improved testability.

As the communications payload lead on Rockwell International's Brilliant Eyes team, Harris Corporation developed a modem which generated a waveform which was very close to the BMD Communications Standard N4 mode required for the GBI. For their Phase I effort with RL, they are modifying their Brilliant Eyes modem to generate the exact GBI waveform. The Brilliant Eyes modem is a fairly large breadboard design, driven in large part on the availability of suitable radiation hardened components. However, adaptation and miniaturization for GBI should yield a much smaller, but still fully radiation hardened modem. Brilliant Eyes required both the N3 and N11 modes. While the Brilliant Eyes N3 mode modem design will be modified to generate the required N4 mode waveform, the N11 mode waveform is completely unnecessary for the GBI application. The elimination of the N11 mode in Harris' modem greatly decreases the complexity of the design. For the F^3 transceiver, the remaining modem functions will be implemented using radiation hardened ASICs.

Supporting Technologies

Low Temperature Growth GaAs

The ballistic missile interceptor application has very stringent requirements for size, weight, and power. Easily the predominant power driver in an EHF transceiver's RF section, the SSPA merits extra attention. Solid state power devices at EHF frequencies typically exhibit relatively poor power added efficiencies and the need to combine several devices to achieve the desired output power result in a power amplifier which is even less efficient. Since only 55 Watts of input power will be available for the entire transceiver aboard the GBI and 5 Watts of output power are needed, power inefficiencies need to be minimized.

In parallel with its efforts to develop transceivers for the GBI, RL and BMDO have also been investing in low temperature growth (LTG) Gallium Arsenide (GaAs) pseudomorphic high electron mobility transistor (pHEMT) technology. Pioneered by MIT's Lincoln Laboratories, LTG GaAs material used as a buffer layer in pHEMT devices has been shown to result in an 8% increase in power added efficiency over conventionally buffered pHEMTs. Theoretically, even greater improvements are possible if LTG GaAs is used for passivation also, but that technology is somewhat further in the future.

One of the goals of RL's LTG investment was to prove that the technology could be transferred to industry. This was successfully proven through Lincoln Lab's industrial partnership with Lockheed Martin Corporation. Consequently, RL has recently begun a contract with Lockheed Martin to design and build a 20 GHz SSPA based on this LTG GaAs buffer layered pHEMT technology. As a result of the increased power added efficiency inherent in this technology, this will be accomplished with a single MMIC. Not only does this approach reduce power consumption, but also helps reduce size and weight. As Figure 5 illustrates, this effort will provide the 6 Watt power MMICs in both unpackaged and packaged forms. Naturally, some power and gain loss is expected from the packaging, but the resulting modules are still expected to beat the 5 Watt EKV output power requirement and therefore offer improved link margin for that application.

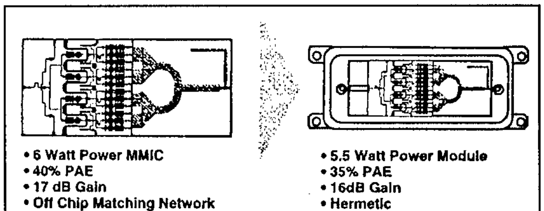

Figure 5 - LTG 20 GHz SSPA

Ground Terminals

While the ground segment of the GBI's communications system may be somewhat less technologically challenging, it is just as important as the interceptor transceiver. Without the ground terminal, there is no way to get the necessary targeting information to the transceiver onboard the interceptor once it has been launched. Unfortunately the program that would develop this ground terminal has been unfunded for the last several years and is only now being revived.

For this reason, RL and BMDO have been making modest investments over the past several years to upgrade a mobile EHF testbed which RL had originally built for the Milstar Program. The testbed is being configured to support GBI flight tests and serve as a precursor to the In-Flight Interceptor Communications System (IFICS) ground terminal which will be used in the operational system.

Upgrades to the terminal in recent years include: installing the terminal on a flatbed trailer to make it more transportable; upgrading the terminal's EHF antenna and controller; adding a Global Positioning System (GPS) receiver, pitch and roll clinometers, and an electronic compass to help automate pointing and tracking; and general convertion of the terminal testbed to a UNIX environment for automated control. The sketches shown in Figure 6 illustrate the current terminal configuration. During the last year, functionality of the terminal was tested by establishing a link with NASA's Advanced Communications Technology Satellite (ACTS). This year's goal is to demonstrate tracking of and communications with a GBI simulator which is based on an EHF Brassboard developed under a previous Rome Lab program.

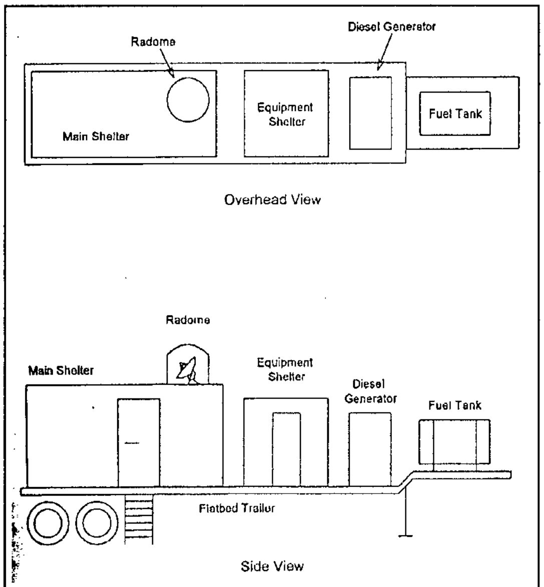

Figure 6 - EHF Mobile Ground Terminal

Future Considerations

While the current NMD architecture requires the GBI to receive its targeting information directly from the IFICS, this may not always be the case. Depending on your point of view, this can be both an advantage and a disadvantage.

On the surface, the idea of sending targeting information directly from the IFICS to the GBI seems like the simplest and optimum approach. After all, the architecture is free of any communications relays which would increase both system cost and communications delays.

However, below the surface, this may not be the case at all. For a single site NMD implementation, no matter where the single site may be, many parts of the United States will be over the horizon from that site and the communications link between the IFICS and the GBI cannot be closed.

Therefore, this architectural concept requires not one IFICS, but a network of IFICSs to ensure the necessary IFICS to GBI communications connectivity. Suddenly, this architecture no longer seems as simple or cost effective.

If we consider the use of a communications relay, probably a satellite but also possibly an aircraft, the potential range of each IFICS is increased and fewer IFICs are needed to provide the necessary coverage. While support for this architectural concept has been politically unpopular in recent years due to potential problems over the Anti-Ballistic Missile Treaty, the opinion that it may eventually be necessary seems to be gaining momentum within the NMD community as of late. This notional NMD concept of operations is illustated in Figure 7.

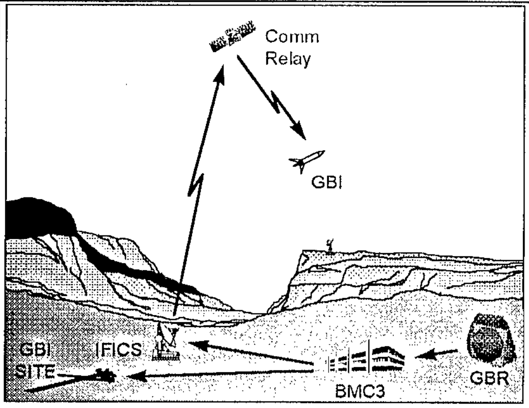

Figure 7 - Notional NMD Concept

Summary

The task of developing a communications system to support the GBI Program is a challenging one, but RL has a sound plan to provide the necessary capability. The GBI EHF transceiver development was divided into two phases. The first phase will provide two functional models of GBI transceivers as well as design plans for building F^3 prototypes. In the current program plan, this first phase is competitive, with TRW and Harris Corporation each developing a functional transceiver and F^3 design plan. The second phase will build the F^3 prototype transceiver(s). Rome Lab has also identified two supporting technologies which are being funded in parallel to the transceiver development: advanced technology for 20GHz SSPAs and EHF ground terminals. This paper describes Rome Laboratory's program plan as well as the technology being used to develop the EHF communications capability required for the GBI mission.

Acknowledgements

This paper was written from a Rome Laboratory perspective, because the author is a Rome Laboratory employee. However, the work described in this paper is very much a team effort with Rome Laboratory as executing agent and BMDO as user. Without support from the user, I would have had nothing to write about. In particular, I should thank my counterpart at BMDO, Maj. Michael Grove, for his strong advocacy and active participation in this program.

This program is also a team effort within Rome Lab. While I am responsible for this project at the PMA Task level, other Rome Lab engineers are responsible at the subtask level. Mr. Joseph Mancini is responsible for our EHF ground terminal work and Mr. Thomas Blake is responsible for our 20 GHz SSPA work. Additionally, Mr. William Cook was responsible for the 20 GHz SSPA work prior to this year and still participates in this program in an advisory capacity. I am responsible for the two transceiver development efforts. If you wish further information on these efforts, you can reach myself at 315-330-4094, Mr. Mancini at 315-330-7130, and Mr. Blake at 315-330-1482.

References

1. "Ballistic Missile Defense Communications Standard (U)," Martin Marietta Corporation, 14 Dec 93. (Secret)

2. "Ground Entry Point (GEP) Requirements for GPALS (U)," GE Aerospace, 29 May 92. (Secret)

3. "National Missile Defense (NMD) Systems Requirement Document (SRD) (U)," Martin Marietta Corporation, 24 Apr 95. (Secret)

4. "Supporting Rationale for Capstone Ballistic Missile Defense Operational Requirements Document (U)," United States Space Command, 9 Dec 94. (Secret)

5. "Technical Requirements Document (TRD) for the Ground Based Interceptor Experiment (GBI-X) (U)," SPARTA Inc., 28 Sep 93. (Secret/Restricted Data)